Abstract—In this paper a high frequency model is developed in PSCAD/EMTDC© to investigate common mode and differential mode phenomena in PWM motor drive, that usually appears when long cables are used to connect the inverter to the motor. A unique model can be used to analyze not only the overvoltage and common mode current phenomena, but also the filter topologies which are utilized to mitigate their associated problems. Simulation analysis of a 3 HP PWM drive is presented. Both high frequency problems and performance of filter topologies are analyzed. Experimental results come along to validate the simulation model.

Index Terms – Overvoltage and Common Mode Filters; Electrical Drive Systems Design and Applications; PSCAD/EMTDC Modeling.

I. INTRODUCTION

The use of IGBT (Insulated Gate Bipolar Transistor) in electrical drive systems has allowed an increase of the PWM (Pulse Width Modulation) carrier frequency and of the semiconductor switching time, improving the performance of the system in terms of current and torque control. However, such changes were accompanied by undesirable electromagnetic interference (EMI) problems, such as overvoltage at motor terminals and circulation of common mode currents. The occurrence of these problems also depends on the cable length that connects the inverter to the motor and the cable and motor characteristic impedances [1], [2], [3], [4].

The overvoltage phenomena and their associated problems have been studied in last decades, resulting in viable filter solutions [5], [6], [7], [8]. Among several possible methods for mitigation of overvoltage and circulation of common mode currents, a common point of study between these methods is to find one topology that could solve the problems listed above together. Methodologies for mitigation of common mode currents departed of already existing dv/dt filters topologies, including appropriate modifications [9], [10], [11], [12], [13].

The achievement of a simulation model, which represents with accuracy the characteristics of the system, the overvoltage and the circulation of common mode currents phenomena, is a critical point. Such a model enables the design, the performance analysis and the optimization of dv/dt and common mode filters.

Among the programs based on EMTP (Electromagnetic Transients Program) utilized to analyze electromagnetic transients in electrical systems, the PSCAD/EMTDC© program was chosen to develop the model of the PWM motor drive system. In this program, there are cable models appropriate for the electromagnetic transients study. In this program, a power cable model located on the ground with distributed parameters and frequency dependent parameters, was formulated and implemented for overvoltage and common mode current analysis in PWM motor drive systems with long cables [14].

The main contribution of this work is to develop a simulation model in the PSCAD/EMTDC© program, representing all the drive system characteristics (inverter-cable-motor). The program has been utilized to investigate strategies that can mitigate overvoltage and common mode current problems. Simulation results of a low voltage 3hp drive system will be presented. Experimental results are also presented validating the simulation model developed.

II. SIMULATION MODEL OF THE PWM DRIVE SYSTEM

The simulation model of the PWM motor drive system developed in PSCAD/EMTDC© includes the models for the inverter, the cable and the motor. Power supply system characteristics (PWM modulation), cable characteristics (size and electrical characteristics) and motor characteristics (low and high frequency parameters) are also included. The Fig.1 presents a schematic design of the model implemented in the program. It’s important to point out that the PSCAD/EMTDC© program is simple to use by having a graphical interface that allows the schematic circuit construction and the simulation process analysis. The simulation results can be managed in an integrated environment. The characteristics and implementation details of drive system are described as follows.

A. Inverter

Considering that the common mode currents circulate through parasitic capacitances present between all elements of
a drive system and their couplings with ground, it’s necessary to represent the capacitances present in the inverter. Therefore, in this model are represented the most important couplings:

- Capacitances of each phase of the inverter to ground;
- Capacitance of the heat sink to ground;
- Capacitance of the DC link to ground.

Both rectifier and inverter are modeled through semiconductor switches (diodes and IGBT) available in the library of the program. The rectifier is an uncontrolled three-phase bridge. The inverter is implemented by a three-phase system using as semiconductor device the IGBT. The sinusoidal PWM modulation is used. The rms value of the input voltage is 220 V and the value of the DC bus capacitance is 2000 µF. In this model it’s possible to implement other forms of the PWM modulation, which is a subject for further analysis.

B. Cables

The cable model is a key point to analyze overvoltage and common mode current circulation phenomena. It is a mandatory requisite that this representation takes into account the distributed nature of the cable and the variation of its parameters with frequency, fully achievable in the PSCAD/EMTDC© program.

The cable model utilized in the system takes into account some fundamental characteristics such as:

- Distributed parameters: takes into account the principle of wave propagation, including attenuation and time delay of the PWM voltage pulse.
- Frequency dependent parameters: calculated for a wide range of frequencies, with higher capacity representation of the physical phenomenon of propagation.
- Phase domain models: determine the dynamic system behavior directly in the phase domain, which are more accurate models.

To implement the cable model, one must determine its physical and electrical characteristics. When choosing the model in phase domain it is necessary to specify the frequency band to be held for the synthesis of rational functions polynomial and the approximate number of poles and residues to be used for determining the characteristic admittance and propagation constant. With respect to physical characteristics, the amount and size of layers of the cable should be defined, and its locations in relation to the ground. The cable was represented by a tetrapolar cable (three phases and a earth wire). It is important to emphasize the importance of correctly setting the cable electric parameters (permittivity and permeability) in the program, since these parameters are intrinsically related to the propagation characteristics of the voltage pulse.

C. Motor

The model of the motor utilized in the simulation is very accurate to represent the overvoltage and common mode current phenomena. In this model, both high and low frequency phenomena are well represented. The low frequency behavior of the motor is obtained using a DQ (Park transformation) dynamic model. The high frequency behavior is obtained...
using a high frequency model, which parameters are described as follows [15], [16]:

- \( R_t, L_t \): network responsible for representing the high frequency phenomena in the turn-to-turn motor wiring;
- \( C_t \): represents the turn-to-ground capacitance;
- \( R_g \): represents the turn-to-ground resistance;
- \( R_e \): responsible for accounting losses in the motor frame.

Table I shows the motor parameters used in the model implemented in the simulation program. It can be observed that the motor impedance to ground at high frequency is very low, since the capacitive coupling is very low. If the motor frame is grounded, there will be circulation of high frequency currents through these couplings, creating electromagnetic interference problems.

<table>
<thead>
<tr>
<th>Motor Nameplate Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>3hp - 230/460V - 3φ - 60Hz - 9/4.5A - 1755rpm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filter</th>
<th>Low Freq.</th>
<th>High Freq.</th>
<th>Inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>40 ( \Omega )</td>
<td>0.42 ( \Omega )</td>
<td>Cg</td>
</tr>
<tr>
<td>L</td>
<td>23 ( \mu H )</td>
<td>0.28 ( \mu H )</td>
<td>Rg</td>
</tr>
<tr>
<td>C</td>
<td>138 ( \mu H )</td>
<td>2.7 ( \mu H )</td>
<td>Re</td>
</tr>
<tr>
<td>Lm</td>
<td>34.8 ( mH )</td>
<td>2.7 ( mH )</td>
<td>Gt</td>
</tr>
<tr>
<td>Lt</td>
<td>2 ( mH )</td>
<td>2 ( mH )</td>
<td>Lt</td>
</tr>
</tbody>
</table>

III. FILTER TOPOLOGIES TO MITIGATE OVERVOLTAGE AND COMMON MODE CURRENTS

Some topologies are suggested in the literature to mitigate, at the same time, overvoltage and common mode current problems and the most important are presented in this work. The filters implemented are basically passive networks associated with certain forms of connection to the inverter DC bus, including common mode inductors. The following topologies are analyzed in the simulation program:

- RLC filter connected at the inverter output (Fig.2) [5], [8].
- RLC filter connected at the inverter output and coupled to DC bus (Fig.3) [9].
- RLC filter connected at the inverter output, coupled to bus DC and including common mode inductor, (Fig.4) [11], [12], [13].

By increasing the rise time of voltage pulse, the the dv/dt rate reduces at the motor terminals and, consequently, the common mode current amplitudes are reduced. Such topologies can reduce about 50% the peak value of the common mode currents.

If further reduction of the the common mode current amplitude is desired, it is proposed to use the RLC filter networks and certain manner of connection to the inverter DC bus. The filter connected to the DC bus is able to reduce both differential mode and common mode currents. The filter consists of an RLC network connected at the inverter output with the filter neutral point connected to the midpoint of DC bus. Herein, it is possible to reduce common mode at the motor terminals as long as it diverts common mode current to the DC bus. The instantaneous and steady state values of common mode current can be reduced by employing appropriate values to components of the filter.

The inclusion of the common mode inductor aims to add a high impedance to common mode, which reduces even more the common mode current amplitudes. The common mode inductor creates a magnetic field that displays a high impedance for common mode signals but low impedance for differential mode signals.

IV. SIMULATIONS RESULTS

This section presents simulations results for the 3 hp motor drive system, using a 20 meters length power cable.

Fig. 5 presents the results for the simulation system without filters. It can be observed that there are transient overvoltages in every switching, with voltage peak arriving at twice as the value of the DC bus voltage, normally expected for this system configuration [4]. Examining the system operation with other cable lengths, it is observed that the oscillations frequency of the voltage transient is reduced as cable length increases. This happens due to the fact that the frequency of transient voltage fluctuations is inversely proportional to the length of the cable. This frequency depends not only on cable length,
but other system characteristics such as propagation speed of the voltage pulse and motor parasitic capacitances. However, these characteristics loose their importance when the cable is long. Fig. 5 also shows the waveforms of the common mode voltage at the motor terminals and the common mode current that flows through the connection to ground. One can check the high common mode current peaks.

Fig. 6 presents the simulation results obtained when a RLC filter is connected to the output of the inverter. One can observe a significant reduction of the overvoltage at the motor terminals. For the common mode, it can be seen a reduction in frequency of oscillation of voltage and current. The common mode current peak was also reduced to about 50% of the nominal value.

Greater attenuation of common mode currents can be obtained when common mode inductors are included in the RLC network, as shown in Fig. 8.

Fig. 7 presents the results when a RLC filter is connected to the inverter output with a coupling to the inverter DC bus. It can be observed, in this case, the significant reduction of oscillations in the common mode voltage and decreasing in the common mode current peak.

V. EXPERIMENTAL RESULTS

A setup of a 3 hp drive system was realized in laboratory in order to validate the simulation results obtained with the PSCAD/EMTDC program.

Figs. 9 and 10 present the experimental results without the use of filters. One can check the overvoltage at the motor terminals and the common mode current waveforms.

Figs. 11 and 12 present the experimental results with the use of the RLC filter connected at the output of the inverter. One can check the voltage attenuation and the reduction of common mode currents.

It can be verified a good correlation between the experimental and the simulation results, validating the simulation model developed in PSCAD/EMTDC. The other filter topologies presented in this paper are being developed in laboratory and their results will be presented in the final version of this work.

VI. CONCLUSIONS

This paper has presented a simulation model of an induction motor drive system developed in the PSCAD/EMTDC program.
program. The simulation model includes inverter, cable and motor representations. This model allows one to analyze the overvoltage phenomena at the motor terminals and the circulation of common mode currents. The model has made possible the analysis of filter topologies which are utilized to mitigate such phenomena.

Simulation results were presented for a low voltage drive system. Filter topologies were also analyzed, demonstrating their capability to mitigate the overvoltage and circulation of common mode currents. Experimental results were also presented validating the simulation model developed showing good agreement. It can be concluded that the simulation model developed is viable to analyze the high frequency phenomena.

Filter topologies that can mitigate, at the same time, overvoltage and common mode current phenomena were also analyzed in simulation and proved to be very effective way to reduce the common mode currents. These topologies are being developed in laboratory. Experimental results of these topologies will be presented in the final work.

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References


